Chapter 10

COMPARATIVE ANALYSIS

VUKAN R. VUCHIC

Selection of the best combination of transit modes is the central decision in planning new or expanding existing transit systems. This decision is very important because it not only determines technological, operational, and network characteristics of the planned system, but through these elements it has a major influence on the role the system will assume in the city's physical, economic, social, and environmental conditions and development. Because of their interdependence, all these factors must be considered in the mode selection, making it a very complex task.

It will be shown that some elements of mode comparison and selection can be quantified and thus compared exactly. Many other elements are qualitative, however, so their evaluation must include considerable experience and value judgments. The procedure, therefore, cannot be defined by a quantitative model nor can the results of the comparative analysis be expressed by a single quantitative value. The desire to simplify this process by using a "mechanized" comparative analysis and basing it on a single criterion (usually cost) has sometimes prevailed, but it usually produced erroneous results, contrary to real-world conditions and experience. Particularly misleading have been the studies based on average values and models of hypothetical situations.

Following a brief review of previous works on transit mode comparison, including its theoretical basis and applications, this chapter defines requirements for transit service, including the three major interested parties and characteristics of different transit modes. Utilizing these concepts, a general methodology of comprehensive transit system evaluation is presented. An example of the application of this methodology is also included.

MODE COMPARISON: STATE OF THE ART AND ITS EVALUATION

The studies involving the comparison of transit modes vary considerably in their approach and purpose, as well as in quality. The most common types of these studies are briefly reviewed here.

An extensive conceptual framework for the comparison of different transit modes was developed by Kuhn.[1] He showed the deficiencies of comparisons based on costs only and emphasized the importance of including not only direct quantitative factors, but also indirect and qualitative ones. He illustrated the methodology by a framework for the comparison of a freeway and a rapid transit line. Hill[2] further developed the concepts for transportation plan evaluation, emphasizing the need to consider different affected groups. He proposed a method for systematic handling of nonquantifiable factors that is comprehensive, but extremely complicated for application. Morlok,[3] Manheim,[4] and several other authors emphasized the need to include all major characteristics ("dimensions") of transit modes into their analysis and evaluation. Following these publications, Thomas and Schofer[5] presented a comprehensive report on the evaluation of transportation plans.

Another set of studies focused on the comparison of actual characteristics of different transit modes. Vuchic[6] analyzed the components of different modes, such as types of rights-of-way, technology (guided versus steered), and vehicle size, and on the basis of their characteristics compared light rail transit (LRT) with several other modes for different sets of conditions (network types, passenger volumes, and so on). Deen and James[7] compared the costs of buses and rapid transit for different types of right-of-way (ROW). Other mode characteristics (comfort, speed, environmental impacts, and the like) were intentionally not included. Lehner[8] presented a comprehensive comparison of all major features of light rail transit and rapid transit, utilizing actual data from many operating systems. Other comprehensive comparisons of actual systems involving different modes (commuter buses on a busway, an extensive bus network, and a rail rapid transit line) that serve similar areas but with different types of service were made by Vuchic and Stanger,[9] and Vuchic and Olanipekun.[10]

A third group of studies is those performed for the actual planning of new transit systems in individual cities. The comprehensiveness of these studies varies greatly. The study for San Francisco Bay Area Rapid Transit (BART) was a relatively simple task since the performance specifications mandated by the legislation were such that only modes operating on exclusive ROW could meet them. The choice of rail technology was logical. An early study for Frankfurt, Germany,[11] analyzed alternative modes with some variations in types of service caused by different characteristics of the compared technologies—monorail, LRT, and rapid transit (see Table 5-1). Since a comparison of alternatives became federally required for transit mode selection in the United States during the 1970s, these studies have become increasingly comprehensive and sophisticated. Examples of such studies are those performed for Baltimore, Rochester and Buffalo (New York), Los Angeles and Sacramento (California), Denver, Edmonton (Canada), Miami, Pittsburgh, Portland (Oregon), Honolulu, Dallas, Houston, and Phoenix (Arizona). These studies have produced a number of excellent conceptual definitions and methodologies for comparisons of modal characteristics.

Finally, several economic studies of mode comparisons have been performed for hypothetical urban corridors, utilizing average costs from different cities or from one specific metropolitan area. Started by Meyer, Kain, and Wohl,[12] this type of study has been followed by several groups of economists, notably including one by the University of California group headed by Keeler and others.[13]

The assumptions and models used in most economic comparisons of modes are so unrealistic that their findings are, in most cases, in sharp variance with the studies of transit in actual cities, mentioned earlier. Their simplistic approach and seemingly clear results, however, give these studies a totally unjustified credibility among some laypersons. It is therefore necessary to discuss briefly the major deficiencies inherent in their methodology.

The economic studies are intended to find optimal domains for individual modes defined by the number of passengers they carry during the peak hour. Actually, choice of mode must be based on a number of factors, such as local conditions, alternative means of travel, service quality throughout the day, and short- and long-term impacts on the served area. Optimal domains of modes in terms of passenger volumes, therefore, are not delineated by a fixed number for all conditions.

The sole criterion used for determining the optimal mode is the minimum cost per passenger-trip. This criterion is valid only in the rare cases when modes with identical level of service (LOS) are compared. In most cases, each mode has a different LOS-cost combination. Thus, if mode I has a lower cost, but also lower LOS than mode II under given conditions, it would be incorrect to conclude that mode I is better because it is cheaper. If the difference in the LOS of mode II is worth its additional cost, mode II is preferred.

A number of important mode characteristics cannot be converted into dollars. But the problem of including these characteristics into mode comparison cannot be solved by elimination of all nonmonetary elements. For example, economic studies often assume that there is sufficient space in central business districts (CBDs) to accommodate freeways and parking facilities for 10,000 or even 30,000 automobiles per hour from a single corridor. Even if this physically infeasible assumption is accepted, the impact of this traffic volume cannot be ignored without making the analysis highly unrealistic.

The computational analysis and the diagrams used by the economic comparisons also have conceptual deficiencies. The basic diagram used presents average cost per trip as a function of passenger volume for different modes, as in Fig. 10-1. Each mode, however, has a different LOS and therefore attracts, under any given set of conditions, a different number of passengers. Rail rapid transit attracts more passengers than does a bus system using busway and streets. Such a bus system, in turn, has a stronger attraction than does a surface bus system. All three systems are so different from the automobile in type of service and potential user groups that their plots on the same diagram have no meaning.

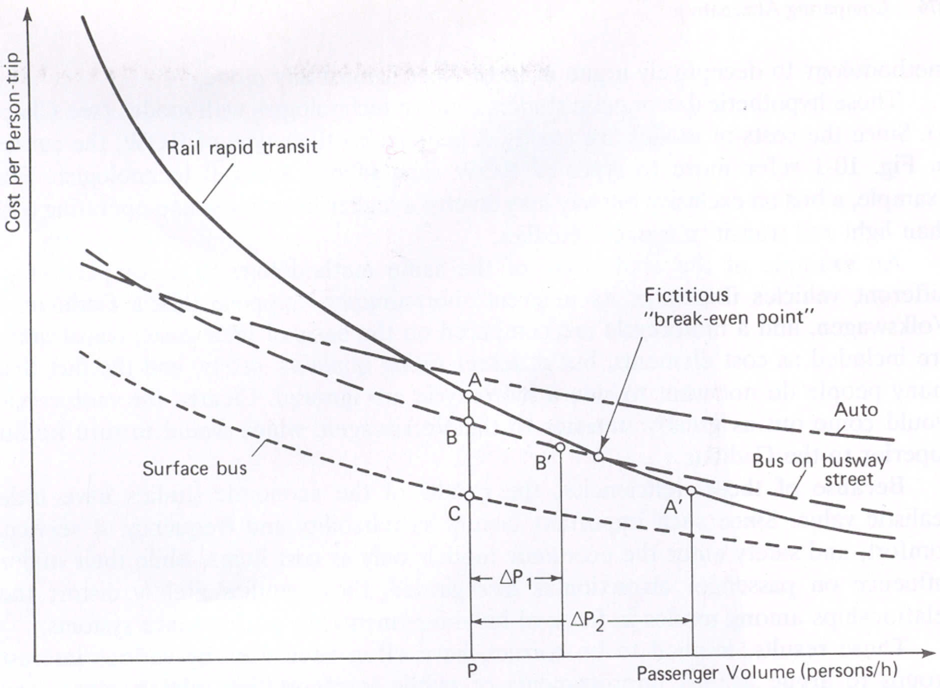

Figure 10-1 *Comparison of modes based on their costs, disregarding differences in level of service and passenger attraction.*

More specifically, the diagram implies that it presents the costs of different modes for any given passenger volume; thus, in Fig. 10-1, cost per trip C for a surface bus appears to compare with cost B for a bus on a busway and street and cost A for rail rapid transit. The fact is that there cannot be a served area in the real world in which these three modes would have the respective unit costs. If a surface bus line would attract P passengers in a given area, then a bus on busway and street would attract a volume $P + \Delta P_1$, and rail rapid transit would attract a volume of $P + \Delta P_2$. Unit cost C therefore should not be compared with costs B or A, but with B′ or A′. Moreover, the criterion is not whether, for example, C is lower or higher than B′, but whether the cost difference B′ − C is worth the attraction of ΔP_1 passengers. Incidentally, this cost difference may sometimes be negative, which makes the higher-quality mode clearly superior even for volumes well below the "break-even point." Actually, the "break-even point" is a fictitious concept: the plotted curves are on different LOS "surfaces" (that is, they cannot be plotted on the same plane, so they do not intersect).

Another problem is that this type of diagram is highly unreliable when it is applied to hypothetical "typical" conditions because of the extreme sensitivity of the curves to the assumptions of the analyst. To change relative positions of curves for different modes by manipulating assumptions of the model is easy. Accordingly, Deen pointed out in his discussion of the study by Miller et al. that the break-even point varied among different studies of this type from the 2000 to 5000 trips/h range to 50,000 trips/h, which is a difference of some 1000%.[14] This characteristic allows use of this methodology to deceptively argue in favor of or against any mode.

These hypothetical economic studies confuse technologies with modes (see Chap. 4). Since the costs of modes are mostly dependent on their type of ROW, the curves in Fig. 10-1 refer more to types of ROW than to bus and rail technologies. For example, a bus on exclusive busway may involve a higher investment and operating cost than light rail transit in a street median.

An example of the application of the same methodology to a comparison of different vehicles illustrates its inherent shortcomings. Suppose that a Cadillac, a Volkswagen, and a motorcycle are compared on the basis of their costs; travel times are included as cost elements, but different riding qualities, safety, and the fact that many people do not want to ride a motorcycle are ignored. Clearly, the motorcycle would come out as greatly superior to the Volkswagen, which would in turn be far superior to the Cadillac.

Because of these deficiencies, the results of the economic studies have little realistic value. Since such important factors as reliability and frequency of service, comfort, and safety enter the economic models only as cost items, while their major influence on passenger attraction is disregarded, these studies greatly distort the relationships among modes in favor of low-investment/low-performance systems.

Those results, implied to be correct, have often been used by various interest groups to argue against improvements of public transportation infrastructure, and particularly rail transit. Their validity, however, has been discredited not only with respect to methodology, but also by real-world events. Comprehensive studies for many cities in this and other countries, previously cited, have clearly shown that real-world conditions are far more complex than the economic hypothetical studies assume: there is a variety of modes—steered and guided—that represent viable alternatives for different cities. A number of cities have found that upgraded buses represent the best solution for many of their corridors (for example, Ottawa, Houston, Pittsburgh); others, or even the same cities, have found that they also have corridors that are best suited to rail transit and that there is a variety of rail modes, rather than one stereotyped "rapid transit." Thus, examples of relatively new successful metro systems include those in San Francisco, Washington, and Atlanta; light rail in Calgary, San Diego, and Portland; and Vancouver's innovative Advanced Light Rail Transit—a fully automated system. This development is continuing in many cities in North America, Europe, and, increasingly, in developing countries.

The diversity of studies comparing transit systems and modes with respect to their assumptions and results is often confusing. An excellent review of the state of the art in this field, with a detailed critical analysis of methodologies used by different authors, was given by Mitric.15 His study analyzed the correctness of both the conceptual basis and methodologies employed by various authors, as well as the validity of their findings. Following a detailed documentation of their shortcomings, Mitric suggested abandonment of economic modal comparisons and presented the basic guidelines that comparisons of modes should follow.

To facilitate an understanding of the individual operating and technical features of urban passenger transportation systems, a growing urban area can be analyzed. The initial condition is a small human settlement with a few dispersed activities and a basic network of paths among them. For this condition, an ideal system of transportation would consist of small vehicles that individual persons or groups would use to travel between different points at the time they desire. The system would be satisfactory in all respects under two conditions: that all persons own vehicles and that everybody can drive them.

If it is supposed that the settlement grows into a small town, then to a city, and finally into a large urbanized area (see Fig. 10-2), it can be shown that, due to increasing volumes of travel, its transportation system would be gradually improved through a sequence of the following steps:

°Introduction of for-hire services by small- and then medium-capacity vehicles (paratransit).

°Introduction of large vehicles as common carriers along the main directions of travel (bus transit).

• Reconstruction of some paths into higher-capacity facilities to accommodate increased traffic volumes (arterial streets, expressways).

°Placement of common carriers on separated ways (first partially, then fully controlled rights-of-way).

°Construction of physical guideways along the controlled ROW, allowing operation of trains with much higher line capacity (LRT, metro, and regional rail).

°Introduction of fully automatic operation of common-carrier vehicles on guideways (AGT, automated metro).

Each of the steps in this evolutionary development of urban transportation would require a certain capital investment, but each would also result in higher capacity, improved service quality, and/or lower operating cost/passenger-km than the preceding systems.

The introduction of higher-performance systems would not necessarily result in elimination of the lower-performance systems; the new systems would serve high volumes of travel with higher efficiency than the preceding systems; thus they would allow those systems to resume the high efficiency of operation they have in their primary domain (that is, at lower volumes of travel).

Owing to the investment required for individual improvements, each successive system tends to have a more limited network than the preceding system. To allow functioning of all models in a coordinated manner, transfer facilities must be provided at various contact points.

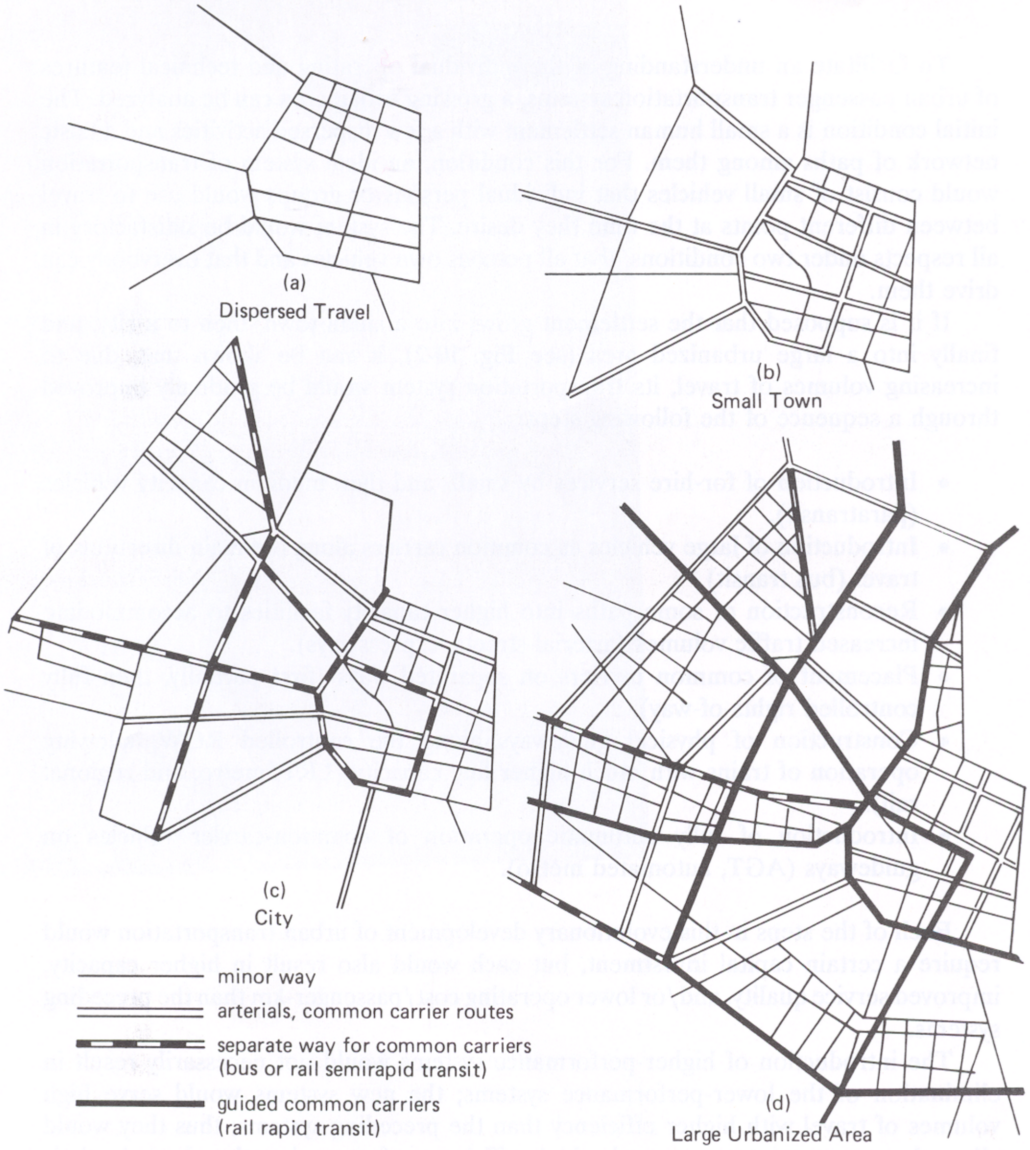

Figure 10-2 *Change of transportation modes with size of human agglomeration.*

This conceptual analysis corresponds very closely to real-world systems. Urban transportation modes ordered by capacity and performance include private automobiles on local streets, buses, construction of arterials (or freeways), introduction of transit lanes, rail systems with partially controlled ROW (LRT), then with fully controlled ROW (RRT), and finally fully automated intermediate capacity or rapid transit systems. The analysis of individual steps in system improvement can clearly show the trade-offs involved in each upgrading. It can also show that each transportation mode has an optimum domain of operation and no single mode could satisfactorily serve all types of travel: the use of each mode outside its "natural" domain results in high cost, low service quality, and undesirable external effects.

METHODOLOGY FOR MODE COMPARISON AND SELECTION

Each city, area, or corridor to be served by a new transit mode has a unique set of characteristics. For selection of the optimal transit mode, it is necessary to define all the site-specific conditions, requirements, and constraints, which are designated as a *conditions set.* This set may by considered as the demand side of the selection process. On the supply side are the transit modes, from which the optimal one should be selected for the specific application. The selection procedure includes the following major phases: the definition of the conditions set, preliminary design of alternative modes for comparison, and the comparative evaluation and selection of the optimal mode.

DEFINITION OF THE CONDITIONS SET

Based on the overall transportation policy for the city or individual area and on the defined goals for the planned system, specific requirements and standards are developed. To ensure a systematic and comprehensive accounting of all system characteristics, requirements for transit systems are classified into three groups by "interested parties": passengers, operator, and community. A definition of requirements must be done with considerable care, since some of them are rather difficult to define precisely or to distinguish from others. Also, some of them may be either somewhat differently defined, expanded, or omitted in specific cases. However, the framework of this type of analysis has a general validity for virtually all modes of transportation. The more similar the compared modes and their studied applications are, the more precise their comparative analysis can and should be.

The various requirements are listed in Table 10-1; they will be defined briefly. Those requirements that are generally common to different interested parties are defined only once, since they differ only for specific cases. These attributes and their definitions closely agree with factors based on users' perceptions cited in Chap. 22.

Passenger Requirements

Availability. This requirement, without which the population cannot use a transit system, has two aspects: *locational,* closeness to a system's terminals, and *temporal,* expressed as frequency of service. For good availability, users must have both reason-

TABLE 10-1
Transit System Requirements

Passenger	Operator	Community
Availability	Area coverage	Level of service/passenger attraction
Punctuality	Frequency	Economic efficiency
Speed/travel time	Speed	Environmental/energy aspects
User cost	Reliability	Social objectives
Comfort	Cost	Long-range impacts
Convenience	Capacity	
Safety and security	Safety	
	Side effects	
	Passenger attraction	

ably close terminals and an adequate frequency of service. Because of cost constraints, trade-offs between the two must often be made. At one extreme is a dense route network with low frequency of service. At the other extreme is frequent service on few routes; users far from terminals do not have the service unless they use feeders. Most urban transit lines utilize a compromise solution: they provide a certain network density and frequency of service. Naturally, with higher demand both can be increased.

Punctuality. Punctuality is defined as schedule adherence. Variance from scheduled times may result from traffic delays, vehicle breakdowns, or adverse weather conditions. Since traffic delays and interference dominate as causes, by far the most significant factor for securing punctuality is control over the system (that is, separation of transit ROW from other traffic).

Speed/travel time. The total door-to-door travel time can be composed of five parts: access, waiting, travel, transfer and departure times. Relative weights of these time intervals vary, since passengers perceive them differently. Therefore, based on various studies reported in literature, a *weighting factor* of 2.0 to 2.5 can be used for waiting and transfer times to obtain perceived travel times. The relative weight of walking time depends heavily on the attractiveness of the area, weather, and other conditions for walking.

User cost. The price of transportation is another important factor for travelers. Transit fare is the most significant portion of it, but other out-of-pocket costs may also be included, particularly for commuters. In a broader sense, cost of access by automobile and even its fixed costs (if an auto is owned only for that purpose) should also be considered in the cost of travel.

Comfort. Comfort is a difficult concept to define precisely because it encompasses many qualitative factors. Paramount are the availability of a seat and the quality of ride (affecting users' ability to read and write). The physical comfort of the seat itself naturlly enters in, as does the geometry of the vehicle entrances and exits, width fo aisles, presence of air conditioning, jerk and noise level, image of passengers relative to one's self-image, and the degree of privacy offered, to name a few.

Convenience. While comfort is related to the vehicle, convenience refers to the overall system. Lack of the necessity to transfer is a convenience. Good off-peak service, clear system information, well-designed and protected waiting facilities, and sufficient, close parking (if required) are all user conveniences. By nature, evaluation of conveniences is predominantly qualitative.

Safety and security. Passenger safety in terms of accident prevention is very important; however, since safety in transit is usually quite high, this aspect is often less important for passengers than protection from crime. Security is measured by statistical records of crime incidents on the system.

Operator Requirements

Area coverage. Area "covered" or served by transit is defined as the area within 5-min walking distance from transit stops for surface transit and the area within 10-min walking distance from stations for rapid transit. Overall area coverage by a transit network can be expressed as the percentage of the urban area which is the transit service area. In examining area coverage, however, in addition to network extensiveness, provision of and for access modes and central business district (CBD) coverage should also be considered.

Frequency. Frequency is expressed by the number of transit unit (vehicle or train) departures per unit itme (hour). It is often incorrectly believed that frequency is not important for commuters. While its significance is greater for off-peak users, it also seriously affects regular riders. For example, there are no residential areas in which only two or three departures during an entire 2-h peak period would be convenient for all potential users. Short, regular headways (that is, high frequency) are an essential element of attracting all categories of passenger trips.

Speed. While passengers are more sensitive to transfer and waiting than travel times, they also prefer high operating speed on the line; the operator is primarily concerned with high cycle speeds on the line, since they affect the fleet size (investment costs), as well as labor, fuel, maintenance, and other operating costs. Consequently, several speeds are used in different analyasis of transit systems:

°Travel speed—one-way average speed of transit units, including stops.
°Cycle speed—average speed, including terminal times.

• Platform speed—overall average speed, including travel to and from garages.

• Pay-time speed—average speed based on drivers' paid time.

Cost. Financial aspects—costs and revenues—often represent the most important single factor of transit system evaluation for the operator. In most cases, three aspects of costs are analyzed: investment cost, operating cost, and revenue. All three vary greatly with local conditions and system characteristics, as well as with time (because of inflation). In evaluation, unit costs rather than total costs of individual modes should be compared.

Capacity. Two different capacities can be defined for a system: way capacity and station capacity. The latter, capacity of lines at stations along the line, governs line capacity since it is smaller in all cases except when vehicles from a line-haul section branch out into several terminals; such cases have few applications at present.

Safety. T he operator must pay attention not only to passenger security, but also to the operational safety of the system. Modes with inherently high safety (controlled ROW, guidance, and fail-safe signal systems are the major factors), therefore, have a major advantage over manually controlled vehicles operated on streets.

Side effects. System effects on the nonusers and the urban environment for which the operator is responsible include such physical impacts as enhancing the aesthetics of an area (for example, through construction of attractive stops or stations) or minimizing noise and air pollution. These effects are achieved not only through careful design of vehicles and infrastructure, but also by attracting travel from private automobiles, which generally have much higher negative side effects on the urban environment per person-kilometer than transit vehicles.

Passenger attraction. The number of passengers that a transit line carries is usually the most important indicator of its success and role in urban transportation. The attraction is obviously a function of the type and level of service, but there is also an additional factor, probably best described as *system image*, which can be very important. This image is difficult to define, but it is composed of such aspects as the simplicity of the system, reliability of service, frequency, and regularity, as well as the physical characteristics of facilities, primary fixed-line facilities (wires for trolleybuses, tracks for rail modes, or separate ROW for any technology), which give it clear visibility and presence in the eyes of users.

Community Requirements

Items included in this category, listed in Table 10-1, are generally self-explanatory. Due to the fact that they consist largely of qualitative, indirect, and long-run effects, their characteristics and relative importance vary from case to case. In each specific case they must be carefully defined and analyzed.

In the United States, comparison of transit modes is a legal requirement for any major transit system investment involving federal funds. The comparisons, designated as Environmental Impact Statements, are comprehensive documents that include not only technical and quantitative comparisons of candidate systems (alternatives), but also, in great detail, all short- and long-run community impacts. These include physical, environmental, historic preservation, economic and social aspects.

DEFINITION OF TRANSIT MODES

As explained in Chap. 4, transit modes are defined by three characteristics: (1) right-of-way category, (2) technology, and (3) type of service.

Right-of-Way Categories

It is reemphasized here that, as shown in Chap. 4, the ROW category is the most important element that influences the performance/cost "package" and thus also the level of service/cost characteristics of individual modes. Transit modes sharing the same facilities with other traffic (ROW category C) can *never* be competitive with the private automobile either in speed or in overall LOS, because transit vehicles are subject to the same traffic delays as automobiles, but, in addition, they must stop for passenger stops along their way. This is true for streetcars, trolleybuses, or buses (that is, regardless of technology). Modes with category B ROW, often designated as semirapid transit (for example, light rail), have a considerably higher speed, reliability, capacity, and so on, than those with category C. The highest LOS in all respects is provided by category A, but at the highest investment cost. This factor usually limits the extent of the network of this category, and requires that it be supplemented by other modes as feeders.

Often the alternatives considered are a smaller network of a higher-performance system with feeders or a larger network of a lower-performance system. Many factors influence this choice, but the basic trade-off from the passenger's point of view is between higher LOS (speed, safety, comfort, and so on) on the former and fewer transfers on the latter. Better area coverage is advantageous, but only if the overall LOS remains above a certain acceptable level. If not, passenger attraction may be drastically reduced. The possibility of system upgrading at a later date into a higher-performance system is also an important consideration in planning. The most important characteristics of the three ROW categories of transit modes are presented in condensed form in Table 10-2.

A particularly important factor in selecting the category is passenger attraction, which is a direct function of LOS, that is, of competitiveness of the transit system with private automobile. The three categories present different investment cost/level of service combinations, as Fig. 10-3 conceptually shows. This diagram is closely related to Fig. 4- 4: the LOS shown here is a direct function of system performance shown in Fig. 4-4.

TABLE 10-2
Characteristics of the Three Right-of-Way Categories

Characteristics	A	B	C
	R/W Categories		
System performance	**Very high**	**High**	**Low**
Service quality	**Very high**	**High**	**Low**
Passenger attraction	**Very high**	**High**	**Low**
Image/identification	**Very good**	**Good**	**Poor**
Impact on urban form	**Very strong**	**Strong**	**Weak**
Investment cost	**Very high**	**High**	**Very low**
Automation possibility	**Full**	**Partial**	**None**

The relationship between LOS and passenger attraction is presented in Figs. 10-4 and 10-5. Figure 10-4 is the conventional diversion curve showing modal split (or distribution of traffic between two highways) as a function of ratio (or difference) of their travel times (or costs). Figure 10-5 shows the same type of diversion curve as a function of transit LOS, which includes such elements as reliability, comfort, and convenience, in addition to travel time and cost. An increase in the total volume of travel, which occurs when LOS increases, is also shown. Assuming that auto travel has a certain fixed LOS for the given direction of travel, the share of transit grows with its LOS. Since LOS is strongly dependent on the ROW category, domains of each category can be plotted along the abscissa with some mutual overlap, as shown. Thus, the diagram shows conceptually the different volumes of passengers attracted by each category of transit modes, the phenomena always observed in cities with buses and rapid transit, or other types of modes with different ROW categories.

The selection of the ROW category is more closely related to the overall characteristics of the transit system, its anticipated relationship with other modes, and economic, social, and other goals of the city than to specific technology and operating characteristics of modes. It is therefore not only a technical, but also a high-level planning and political decision. Conversely, the selection of a ROW category does influence the technology: for category C, bus is usually the optimal choice; as the separation of transit ROW increases, rail becomes more advantageous; when ROW A is used, rail technology completely dominates for a number of physical, operational, and network reasons.

Technology and Type of Service

The next step in the comparison and selection of modes focuses on determination of the technologies and types of service for candidate modes. Two groups of technology are most commonly used: highway and rail. Other systems can be classified into

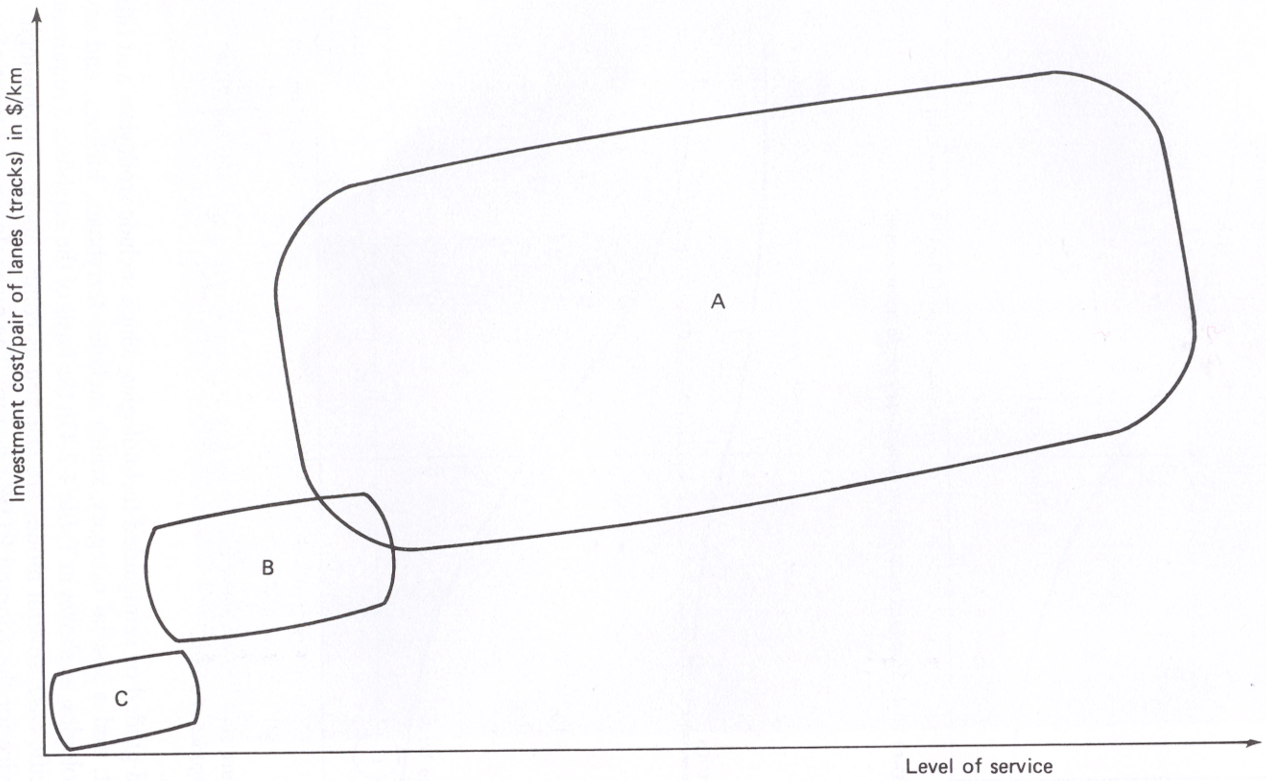

Figure 10-3 *Level of service/investment cost relationship for transit modes with different right-of-way categories.*

Comparative analysis of different technologies within the same ROW category is based primarily on a deeper analysis of specific technical and operating system characteristics, and somewhat less on the overall system impact. The analysis is therefore predominantly technical. It is better defined and more quantitative than the one of ROW categories, and yet it is far from simple: it must include a great number of factors, both quantitative and qualitative, and evaluate all of them.

Selection and Functional Design of Candidate Modes

In each specific case of transit mode selection, the engineer—planners must select candidate modes on the basis of an examination of the conditions set for the planned system and a knowledge of the characteristics of different ROW types, transit technologies, and operations. Planners select those modes that may conceivably satisfy the defined requirements. The more expertise and experience planners have, the more precise their choice, and the fewer candidate modes they will select. Accordingly, in no case will an experienced transit planner compare such drastically different modes as buses on street and rapid transit, automated guided transit and minibuses, or dial-a-ride and light rail: the condition sets making the application of the former modes likely will clearly not be suitable for use by the latter ones.

Once these candidate modes are selected, a functional design must be developed for each. The network, specific technology, and operation must be determined so that they are compatible with the given conditions. This preliminary design is necessary since different characteristics of modes make their optimal employments different. For example, rapid transit, light rail, regional rail, and buses on busways would each have its own optimal station locations, connections with other modes, and so on.

THE EVALUATION PROCEDURE

Each candidate mode must now be evaluated with respect to each requirement. The type and depth of evaluation that are reasonable and practical with respect to data availability and objectivity of evaluation of qualitative aspects should be determined. The evaluation of each parameter can be expressed in one of three basic ways: (1) monetary units of measure (dollars), (2) other quantifiable units, or (3) qualitative evaluation.

To derive an overall evaluation of different modes expressed by a single quantitative criterion, two highly subjective and therefore potentially controversial steps have to be made. First, all parameter evaluations have to be quantified; and, second, their relative weights have to be assumed. Although in some rather simple cases this can be done with reasonably satisfactory results, in transit system evaluations this is seldom the case. The reader, analyst, or decision maker will usually get a better picture of compared modes through a complete list of evaluated items than if presented with a single number based on numerous subjective values that often cannot be tracked down.

An Example

An example of this type of comparative analysis is presented in an abbreviated form in a complex comparison of a rapid transit line (Lindenwold) with express bus service (Shirley Express)—modes with different ROW categories, different technologies, and, related to these, different types of service. Although extensive quantitative analyses were made, it was considered that the numbers could sometimes be misleading because the lines operate under similar, but not identical, conditions sets. Therefore, the final comparative evaluations were made in qualitative terms. The results of the comparison are summarized in Table 10-3. This evaluation was

TABLE 10-3
Summary of Comparative Analysis:
Lindenwold Rail Line and Shirley Busway

Requirement	Lindenwold	Shirley	Higher-Rated System
Passenger			
Availability	Good	Poor	Lindenwold
Speed-travel time	Good	Very good	Shirley
Reliability	Very good	Poor	Lindenwold
User cost	Good	Very good	Shirley
Comfort	Good	Poor	Lindenwold
Convenience	Good	Fair	Lindenwold
Safety and security	Very good	Good	Lindenwold
Operator			
Area coverage	Good	Very good	Shirley
Frequency	Very good	Very good	Lindenwold
Speed	Very good		
Cost: investment	Very Poor	Fair	Shirley
Cost: operating	Good	Poor	Lindenwold
Capacity	Good	Poor	Lindenwold
Side effects	Good	Fair	Lindenwold
Passenger attraction	Very good	Good	Lindenwold
Community			
System impact	Very good	Good	Lindenwold

Source: V. R Vuchic and R. M. Stanger, "Lindenwold Rail Line and Shirley Busway A Comparison," in *Evaluation of Bus Transit Strategies*, Highway Research Record 459 (Washington, D.C.: Highway Research Board), pp. 13-28.

supplemented by a description of the analysis of each parameter supported by all important data relevant to it. The findings show more clearly the causes of a 70% higher passenger attraction by the Lindenwold rail line than a comparison limited to cost and travel time only could explain. The study separated differences caused by different local conditions from those caused by inherent characteristics of rail and bus technologies, ROW categories, and types of operations.

A similar comparison of two existing systems was performed by Vuchic and Olanipekun16, on the Lindenwold rail line and New Jersey Transit (NJT) buses. The difference from the preceding study was that these two modes are even more different than Lindenwold and Shirley: NJT buses do not have ROW B—they operate on streets and freeways in mixed traffic. This makes the comparison more difficult. On the other hand, the two systems serve the same general area, so the local conditions are virtually identical. The comparison showed the drastic differences in the types of services buses and rapid transit provide. As a result of these differences, passenger attraction is very different: due to its very high LOS, the single rapid transit line, Lindenwold, attracts a 43% greater ridership than 26 bus lines, which have a much more extensive area coverage, but significantly inferior type and level of service. The rail line has a 44% higher cost recovery ratio (operating revenue/operating expenses) than the bus lines.

SUMMARY AND CONCLUSIONS

In summary, the procedure for the comparative analysis and selection of transportation modes follows these major steps.

- *Step 1:* Based on urban transportation *policy,* develop *goals* for the transit system.
- *Step 2:* Define *conditions* for the area to be served.
- *Step 3:* Utilizing results from preceding steps, define specific *requirements and standards* for the planned system.
- *Step 4:* Select *ROW type* for candidate modes.
- *Step 5:* Select *technologies* and *type of operation* for candidate modes.
- *Step 6:* Develop *functional designs* for candidate modes.
- *Step 7: Evaluate* candidate modes.
- *Step 8: Compare* evaluation results and *select* the optimal mode.

In conclusion, it must be stated that a comparative analysis of transit modes is a very complex problem. There is often a strong tendency to simplify this process, even to the extent that only a single item (usually cost) of peak-hour operation is used as the sole evaluation criterion. Considerable literature exists on "thresholds" of individual technologies, often not recognizing the importance of ROW types and of a great number of performance and LOS characteristics. This tendency for simplification has, in combination with pursuit of a wrong objective in transit system planning (to provide the minimum-cost system), led to many incorrect decisions.

Different transit modes must be compared in a systematic manner and on a comprehensive basis, utilizing many different factors. The methodology presented here facilitates the comparison by classifying transit systems first by their ROW type, affecting strongly their LOS, then by technology, and then by type of operation.

Although the methodology is not exact due to many subjective elements that must be included, it is greatly superior to the simplistic comparisons based on system costs only.

It should be expected that further work and experience with the methodology outlined here will bring additional improvements. However, these improvements should not be expected in the quantification of individual parameters and mechanization of the evaluation procedure, which is usually accompanied by a reduction in an understanding of systems. Rather, the improvements should be made in further formalization of a systematic methodology and comprehensive approach, which will require a much better understanding of transit systems, their operations, and their role in urban transportation than is presently the case.

REFERENCES

1 TILLO E. KUHN, *Public Enterprise Economics and Transport Problems* (Berkeley, Calif.: University of California Press, 1962).

2 Morris HILL, HA Method for the Evaluation of Transportation Plans," in *Transportation System Analysis and Evaluation of Alternate Plans,* Highway Research Record 180 (Washington, D.C.: Highway Research Board, 1967), pp. 21-34.

3 EDWARD K. MORLOK, "The Comparison of Transport Technologies," in *Transportation System Evaluation,* Highway Research Record 238 (Washington, D.C.: Highway Research Board, 1968), pp. 1-22.

4 MARVIN L. MANHEIM, "Principles of Transport Systems Analysis," in *Transportation System Analysis and Evaluation of Alternate Plans,* Highway Research Record 180 (Washington, D.C.: Highway Research Board, 1967), pp. 11-20.

5 EDWIN N. THOMAS AND JOSEPH L. SCHOFER, *Strategies for the Evaluation of Alternative Transportation Plans,* NCHRP Report 96 (Washington, D.C.: Highway Research Board, 1970).

6 VUKAN R VUCHIC, "Place of Light Rail in the Family of Transit Modes," in *Light Rail Transit,* proceedings of a national conference, June 23-25, 1975, Special Report 161 (Washington, D.C.: Transportation Research Board, 1975), pp. 62-76.

7 THOMAS B. DEEN AND DONALD H. JAMES, "Relative Costs of Bus and Rail Transit Systems," in *Transportation Systems Planning,* Highway Research Record 293 (Washington, D.C.: Highway Research Board, 1969), pp. 33-53.

8 FRIEDRICH LEHNER, "Light Rail and Rapid Transit," in *Light Rail Transit,* proceedings of a national conference, June 23-25, 1975, Special Report 161 (Washington, D.C.: Transportation Research Board, 1975), pp. 37-49.

9 V. R. VUCHIC AND R. M. STANGER, "Lindenwold Rail Line and Shirley Busway : A Comparison," in *Evaluation of Bus Transit Strategies,* Highway Research Record 459 (Washington, D.C.: Highway Research Board, 1973), pp. 13-28.

10 VUKAN R. VUCHIC AND OLAYINKA A. OLANIPEKUN, “Lindenwold Rail Line and New Jersey Transit Buses: A Comparison," in *Urban Public Transportation Research 1990*, Transportation Research Record 1266, Public Transit (Washington, D.C.: Transportation Research Board, 1990), pp. 123-38.

11 WOLFGANG S. HOMBURGER, "An Analysis of Different Forms of Rapid Transit," in *Urban Mass Transit Planning* (Berkeley, Calif.: University of California, Institute of Transportation and Traffic Engineering, 1967), pp. 197-203. A summary of a report by K. Leibbrand for Frankfurt, Germany.

12 J. R. MEYER, J. F. KAIN, AND M. WOHL, *The Urban Transportation Problem* (Cambridge, Mass.: Harvard University Press, 1966).

13 THEODORE E. KEELER AND OTHERS, The *Full Costs of Urban Transport*, a series of monographs (Berkeley, Calif.: University of California, Institute of Urban and Regional Development, 1974-1975).

14 D. R. MILLER AND OTHERS, "Cost Comparison of Busway and Railway Rapid Transit," with discussions, in *Evaluation of Bus Transit Strategies*, Highway Research Record 459 (Washington, D.C: Highway Research Board, 1973), pp. 1-10.

15 SLOBODAN MITRIC, *Comparison of Modes in Urban Transport: A Methodological Analysis*, Technical Report (Columbus, Ohio: Ohio State University, Department of Civil Engineering, July 1976). A summary entitled "Comparing Modes in Urban Transportations“a appears in *Transportation Evaluation Techniques*, Transportation Research Record 639 (Washington, D.C.: Transportation Research Board, 1977), pp. 19-24.

16 VUCHIC AND OLANIPEKUN, "Lindenwold Rail Line."

EXERCISES

10-1 A number of studies have been made with the purpose of finding which modes are "better" than others. Typically, the focus has been on the bus versus rail question, using peak-hour passenger volume as the only variable. Is this problem formulated correctly? What is the answer to it, and under what conditions can there be a correct answer?

10-2 What are the typical problems with comparisons of transit modes based on hypothetical models of cities and analyses of costs only? Which type of modes do these studies tend to evaluate unrealistically highly, which modes are usually unjustifiably downgraded and why?

10-3 Compare major modes of higher-quality bus transit: express bus, semirapid bus, and guided bus (O-Bahn) with regular bus, using their basic characteristics (that is, those conditions independent of local conditions).

10-4 There are opinions that light rail transit (LRT) can have performance similar to that of rapid transit, but it requires much lower investment. Contrary claims are that LRT compromises many operational features because it does not have exclusive ROW, so it is not much better than conventional streetcars. Define the basic characteristics in which the three modes differ and compare them. Evaluate the two opinions and express your conclusions about the merits of LRT compared to streetcars and to rapid transit.

10-5 Define the following characteristics of transit modes: travel speed, flexibility, long- range impacts, comfort.

10-6 Which transit mode characteristics are included in "side effects"?